Field Monitoring and Analysis on Vibration and Noise Characteristics of AC Transformer Caused by ±660kV Yin-dong DC System

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Abstract

Yin-dong ±660 kV High Voltage Direct Current (HVDC) Power Transmission Project, the first ±660 kV DC transmission project built around the world, is the symbolic project at this voltage level and a major transmission line of Shandong grid. When the HVDC system is operated in monopole ground return mode, the vibration and noise of the ac power transformer will get enhanced during field monitoring. This paper describes the abnormal vibration and noise in detail. By analyzing the abnormal phenomena and monitoring the direct current passing through the neutral point of transformer, this paper shows that the main reason is the monopole grounding operation of Yin-dong DC system. Finally, measures are provided to prevent the occurrence of abnormal vibration and noise of alternating current (AC) power transformers.

Keywords

Dc Power Transmission; Transformer; Dc Magnetic Bias; Noise

Introduction

Yin-dong ±660 kV DC power transmission project, the first ±660 kV DC transmission project built around the world, is the symbolic project at this voltage level and a major transmission line of Shandong grid which has a rated capacity of 4000 MW. When one pole was put into operation on October 28, 2010, the vibration and noise of the AC power transformer got enhanced abnormally without resolution. Further analysis is urgently needed.

Large power transformers make great noise and cooling auxiliary devices. Transformer noise is mainly produced by the iron core, winding and oil box (including magnetic shielding) while the noise of cooling auxiliary devices is mainly produced by the fan and oil pump. Transformer noise not only pollutes the environment, endangers people's health and affects the normal operation of the equipment, but also has an influence on the occupied area of the substation. For a transformer, noise, as well as electrical and mechanical properties, is a technical parameter of great importance.

Recently, with the increase of DC transmission, it is well known that when an HVDC system is operated in the monopole ground return mode, the vibration and noise levels of AC power transformers neighboring the DC grounding electrode increase [1]-[3]. By analyzing the abnormal phenomena in Shandong power grid and comparison with the measured current data in the transformer's neutral point, this paper concludes that the mainly reason is the monopole grounding operation of Yin-dong DC system, which affects the normal operation of the equipment.

The Abnormal Vibration and Noise of the Transformer

When the Yin-dong DC was operated at full load under the monopole mode on November 8, 2010, the No.3 main transformer (operated with neutral point grounding) in Rizhao substation, and the No.5 main transformer (operated with neutral point grounding) in Huangdao substation ran with their obvious enhanced vibration and noise. The result of site test showed that the noise of No.3 main transformer had 15~20dB stronger than that of the No.4 main transformer (operated with neutral point non-grounding) in Rizhao substation and the average vibration displacement of the No.3 main transformer was 13.3 um while that of No.4 main transformer was 4.4 um.

In the morning of November 12, 2010, the noise and vibration of No.3 main transformer in Rizhao substation and No.5 main transformer in Huangdao substation got enhanced significantly. Around 10 o 'clock, Yin-dong DC changed the operation mode from the monopole ground run (GR) to the monopole metal loop run (MR), and subsequently the vibration and noise of the main transformers in Rizhao and Huangdao substations returned to normal. At 16 o 'clock, on November 12, Yin-dong DC changed the

operation mode from MR to GR, and result of site test showed that the noise of No.3 main transformer in Rizhao substation increased from 78 dB to 95 dB and that of No.5 main transformer in Huangdao substation increased from 77 dB to 87 dB. During that time, Weifang substation reported that the vibration and noise of No.3 main transformer increasedgreatly.

Meanwhile, when the Yin-dong DC was operated under monopole ground return mode, 500 kV Laoshan substation, Daze Substation and Mizhou substation all reported that the transformers' vibration and noise was enhanced to some extent.

Analysis of Transformer'S Abnormal Vibration and Noise

The reasons that large power transformers have abnormal vibration and noise usually include some aspects as following.

(1)The auxiliary devices such as fan, oil pump, etc., operate abnormally.

(2) Loose of some components inside the transformer.

(3)The abnormal hysteresis expansion of the transformer iron core.

Related workers in Rizhao and Huangdao substations found out auxiliary devices of main transformers operated normally when the abnormal vibration and noise occurred. Because the vibration and noise were discontinuous, the second aspect could be ignored. So it can be concluded that the abnormal hysteresis expansion of transformer iron core is the preliminary reason.

The reasons that lead to abnormal hysteresis expansion of transformers are listed as following:

(1) Weaknesses inside transformer mainly include: loose on the aspects of core lamination; of the magnetic shielding; of winding or turn to turn short circuit, open circuit; core grounding;

(2) Abnormal AC power sources mainly include: harmonic current out of range; abnormal frequency, large frequency fluctuation; large voltage fluctuation.

(3) DC magnetic bias. DC magnetic bias, an abnormal state for transformer, means that the transformer's field current includes DC component, which will cause core saturation and change the magnetic path. As a result, it may lead to abnormal hysteresis expansion of transformers.

After the test of related substation workers' field, it was found that the AC power source was normal when the main transformer's noise was abnormal. Meanwhile, considering the main transformer's abnormal noise is discontinuous, the weaknesses inside transformer leading to the abnormal hysteresis expansion can be ignored. The two main reasons that may lead to transformers' DC magnetic bias are as following:

(1) It may cause DC magnetic bias in the transformers near the grounding pole when the DC transmission is operated in the monopole mode [4], [5].

(2)When magnetic storm happens, the alteration of geomagnetic field will induce the earth surface potential (ESP) producing the geomagnetic induced current (GIC) in the loop which consist of transmission line, transformers with neutral point grounding and the earth. The frequency of GIC is 0.001 ~ 0.1Hz, and this quasi DC also can cause transformer's DC magnetic bias saturation [5], [6].

According to the analysis of the related geomagnetic field data provided by geomagnetic observatory, the magnetic storm didn't occur when the transformer vibration and noise were abnormal. Thus the influence caused by the magnetic storm can be ignored.

According to the analysis above, it can be preliminarily concluded that the Yin-dong DC monopole grounding operation is possibly the reason of transformers' abnormal vibration and noise.

The Influence Mechanism and Monitoring Data Analysis

When Yin-dong DC was operatef under monopole grounding mode, the earth acted as a part of the loop, and more than 1000 A direct current would flow into the earth through the grounding pole. As a result, the surface potential near the grounding pole becomes higher. With the increase of the distance to the grounding pole, the surface potential reduced gradually, which leads to varying surface potential in different places. In the Extra High Voltage Grid, in order to provide security, the neutral point is grounded in the high voltage side with large power transformer. Meanwhile, the surface potential difference will interact between the grounding neutral points of two transformers. Then the direct current is produced in the loop as shown in figure 1.

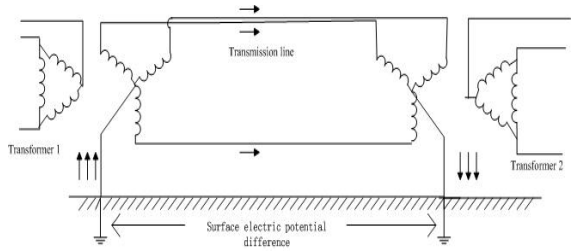

FIG. 1 SCHEMATIC DIAGRAM OF DIRECT CURRENTS GENERATING AT THE NEUTRAL POINT OF TRANSFORMERS

The iron core of large power transformer is piled up by the silicon-steel plates, whose magnetic conductivity is nonlinear. The B-H curve of silicon-steel plate is shown in figure 2. In order to reduce the volume of transformer and economize the core material, the transformer rate working point is always set at the inflection point between the linear zone and the saturation zone, just as the point 'an' in figure 2. The DC bias flux could be produced in the core of the transformer when the direct current flows through the transformer windings, which will make the transformer's working point into a saturation zone, just as the point 'b' in figure 2, leading to the half wave saturation of transformers. This phenomenon is called transformer DC magnetic bias.

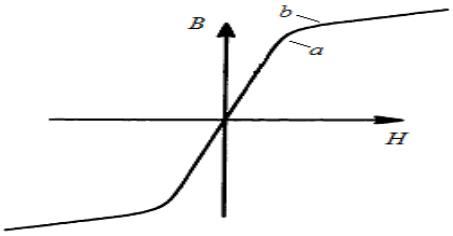

FIG. 2 B-H CURVE OF IRON CORE MATERIAL

The half wave saturation of a transformer can enhance the magnetization intensity of the iron core material. Consequently, it can strengthen the icon core hysteresis expansion of the transformer, which can enlarge the vibration and noise.

In order to further prove that it is the Yin-dong DC monopole grounding operation which leads to the transformers' abnormal vibration and noise in Shandong power grid, related workers have tested the corresponding DC through the neutral point and the corresponding noise of No.3 main transformer in Rizhao substation and No.5 main transformer in Huangdao substation. The test result is shown as Table 1.

Just as shown in the Table 1, approximately 10 A direct current monitored flowed into the neutral points of the two transformers (No.3 main transformer in Rizhao substation and No.5 main transformer at Huangdao substation). The intensity of the noise is 10 dB stronger than normal status. No.3 main transformer at Rizhao substation is even 20 dB stronger than before.

According to the analysis on the monitoring data, it can be proved that the transformers' abnormal vibration and noise are caused by DC magnetic bias in Shandong grid, which is the result of Yin-dong DC monopole grounding operation.

TABLE 1. MONITORING DATA OF NOISE AND DIRECT CURRENT AT THE NEUTRAL POINT OF TRANSFORMER

Name of the main transformer	DC through the neutral point	Transformer noise intensity	
		Operate normally	DC through the neutral point
No.3 main transformer in Rizhao substation	13.9A	78dB	95dB
No.5 main transformer in Huangdao substation	9.6A	77dB	87dB

The Harmness of Transformer DC Magnetic Bias

Transformer DC magnetic bias can enhance the transformer's vibration and noise, which can make the transformer's internal fasteners loose, and cause potential threats to the safety of operation of transformers.

Because of the nonlinearity of the transformer iron core, the DC magnetic bias can increase the transformer's field current and the harmonic current, resulting in the consumption of more reactive power and also making the system voltage lower, which will lead to the reactive power fluctuation and false actions of relay protection. Meanwhile, it will make the SVC overload and trip. All the above influences will threaten the grid's safety operation seriously [7], [8]. The increasing field current will also make extra loss and temperature of the transformer winding increase, which is harmful to the transformer's safe operation.

In addition, when the transformer is operated normally, the magnetic flow through the main magnetic circuit in the core, and the leakage flux is less. When the transformer is half wave saturation, the working point enters the saturation zone, which reduces the core magnetic conductivity. As a result, amounts of leakage flux flow into the metal components of transformers, such as the oil tank wall, iron core clamp. It can also cause extra loss and increase the temperature of the

transformer, which makes negative influences on the transformer's safe operation [9]-[12]. The increasing transformer temperature can accelerate the insulating material aging, reduce the transformer's service life, and make the oil-immersed transformer produce more methane, ethane, and other harmful gas.

Conclusion

As it has been mentioned abovethat Yin-dong DC monopole grounding operation causes these abnormal vibrations and noise of transformer in Shandong Grid. Besides the abnormal vibration and noise, Yin-dong DC also can result in the overheating of transformer local, which can threaten the transformer's safety operation. Taking into account the above, several suggestions are given as following.

(1) Developing on-line monitoring system to monitor the transformer neutral point's current, noise and vibration in Rizhao substation, Huangdao substation, etc. which are greatly affected by the Yin-dong DC monopole grounding operation.

(2) According to the detailed measured data supplied by the monitoring system, the vibration and noise characteristics of the monitored transformer have been analyzed, and the noise limiting value under the condition of magnetic bias is also determined. This measure can control the direct current within tolerance of the transformer.

(3) Install DC magnetic bias suppression device for transformers which are greatly affected by Yin-dong DC.

(4) Install noise reduction device inside transformers which are greatly affected by Yin-dong DC to improve the acoustic environment in and around the substation.

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